

Research on Piezoelectric Generators for Vibration Energy Harvesting

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Abstract. Ambient energy harvesting has been in recent years the recurring object of a number of research efforts aimed at providing an autonomous solution to the powering of small scale electronic mobile devices. Among the different solutions, vibration energy harvesting has played a major role due to the almost universal presence of mechanical vibrations. In the paper, a piezoelectric cantilever device for harvesting the ambient low-frequency vibration energy is designed, and influences of its structure on output voltage and power generation capacity are studied also. The study results show that the piezoelectric cantilever can produce enough power energy which meets the operation requirements of sensors in wireless networks. It provides a method and corresponding theoretical basis for the harvesting of ambient low-frequency vibration energy and the design of self-supply devices for sensors in wireless networks.

Introduction

Recent developments in power electronics have reduced the power requirements of small electronic components (such as the wireless sensors used in structural health monitoring) and motivated the research on powering these devices by using the vibration energy available in their environment. [1] The ultimate goal is to remove the external power source or battery replacement requirement for such small electronic devices, especially in remote locations. The basic transduction mechanisms that can be used to convert the ambient vibration energy to electrical energy are electromagnetic, electrostatic and piezoelectric transductions. [2] Among these transduction mechanisms, piezoelectric transduction has received the greatest attention in the past few years. [3-5] One method of power harvesting is to use piezoelectric materials (PZT), which form transducers that are able to interchange electrical energy and mechanical strain or force. Therefore, these materials can be used as mechanisms to transfer ambient motion (usually vibration) into electrical energy that may be stored and used to power other devices. By implementing power harvesting devices, portable systems can be developed that do not depend on traditional methods for providing power, such as the battery, which has a limited operating life. [6] How to design energy harvesting device, effectively harvesting vibration in the low frequency range within the environment can improve the power generation capacity, is the key to the study of technology. [7] The author uses a piezoelectric cantilever structures to harvest vibrational energy, to study the effect of its transformation and generation capacity. The purpose of this paper is to investigate the modeling and design of a piezoelectric vibration-to-electricity converter to be used as a power source for wireless electronics.

Piezoelectric device generating mechanism

Piezoelectric ceramics have been used in many applications for many years to convert mechanical energy into electrical energy. The direct piezoelectric effect was early demonstrated by Jacques and Pierre Curie in 1880. They found that when certain ceramic crystals were subjected to mechanical strain, they became electrically polarized and the degree of polarization was proportional to the applied strain. Conversely, these materials deform when exposed to an electric field.

The origin of the piezoelectric phenomenon is due to the asymmetry in the cell unit of the material. When it is subjected to mechanical distortion along one direction, aligned electric dipoles are formed

due to spontaneous separation of electronic clouds from their individual atomic center and this lead to a macroscopic net polarization of the crystal lattice. The compressive and tensile stresses along one single direction will generate a parallel electric field and a consequent force that opposes to the length variation. It is also reciprocal, the same crystal exposed to an electric potential will experience anelastic strain causing its length to decrease or increase according to the field polarity. Each of these effects results almost linear within small length variation relative to the crystal size.

The coupling between the electrical and mechanical behaviour of the material has been approximated by static linear relations between electrical and mechanical variables:

$$\begin{cases} S = s^E T + dE \\ D = dT + \epsilon^T E \end{cases}$$

where: S is a strain tensor, T is a stress tensor, E is an electric field vector, D is an electric displacement vector, s^E is an elastic compliance matrix when subjected to a constant electric field E , d is a matrix of piezoelectric constants, ϵ^T is a permittivity measured at a constant stress. [8-10]

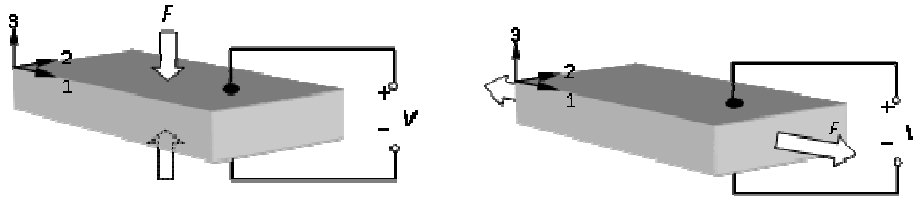


Figure1 Illustration of 33 mode and 31 mode operation of piezoelectric material

Figure1 illustrates the two different modes in which piezoelectric material is generally used. The x, y, and z axes are labeled 1, 2, and 3. Typically, piezoelectric material is used in the 33 mode, meaning that both the voltage and stress act in the 3 direction. However, the material can also be operated in the 31 mode, meaning that the voltage acts in the 3 direction (i.e. the material is poled in the 3 direction), and the mechanical stress/strain acts in the 1 direction. Operation in 31 mode leads to the use of thin bending elements in which a large strain in the 1 direction is developed due to bending. The most common type of 31 elements is bimorphs, in which two separate sheets are bonded together, sometimes with a center shim in between them.

Analysis for Piezoelectric Generators

Figure 2 shows the basic piezoelectric energy harvester configurations (unimorph and bimorph) under base excitation. The conductive electrodes covering the top and the bottom faces of the piezoceramic layer(s) are connected to a resistive electrical load. Note that, depending on the poling direction of the piezoceramic layers and combination of the electrode leads, the piezoceramic layers of the bimorph configuration can be combined either in series or in parallel.

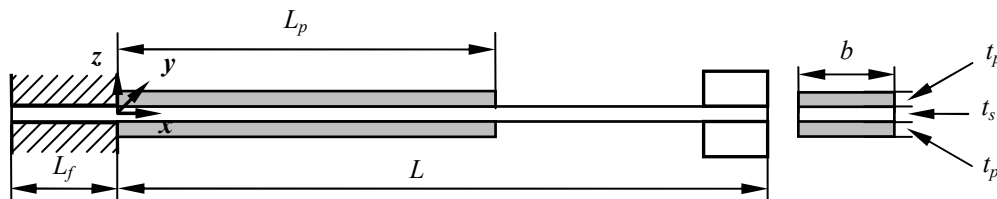


Figure 2 Cantilever piezoelectric energy harvester configurations

Based on the optimized cantilever harvesters, one array harvester has been made. Next, a low-power temperature sensor and a wireless module are selected and the wireless sensor powered by piezoelectric energy harvesting is completed.

Studies have been conducted to explore the possibility of using piezoelectric power harvesting devices to provide energy to wireless sensor circuit. In this paper, the wireless sensor circuit power consumption and piezoelectric energy harvesting generating property was tested. For the wireless sensor circuit, power supply for supplying power to the 5V circuit power consumption as its power, were tested in parallel SSHI control method of opening and closing, RF at different rates when data is transmitted power. For the piezoelectric energy harvesting, at 4.8V, 60mAh nickel cadmium rechargeable batteries for load, measured obtaining the output current when the battery charge to calculate the output power in appropriate frequency and excitation. The piezoelectric energy harvesting can be used the parallel SSHI control method; the output power can be measured when control methods work and do not work. The experiment is conducted and the result shows that the harvester can supply necessary energy to power wireless sensor to transmit temperature data at a certain frequency.

Conclusions

Piezoelectric generators for vibration energy harvesting have received more attention due to their self-contained power generation capability, i.e., they do not require an external voltage source, high energy density, and good dynamic response, and ability to scavenge energy in the range of 1 to 200 $\mu\text{W}/\text{cm}^3$ (possibly higher in the near future as optimized designs and improved piezoelectric materials become available) from ambient vibration energy sources, this power level is suitable for an average consumption of approximately 100 μW ; hence, it is particularly suitable for wireless sensors and communication nodes. Piezoelectric generators often take the form of a cantilever with a seismic mass and a sandwich structure. This is because a device configured as such, working in the first bending mode with a lower stiffness, offers a lower resonant frequency, which can be easily matched to the target ambient vibration frequency for maximum power generation. The power output of piezoelectric generators dictates device suitability for most applications. As such, the evaluation of the power output of piezoelectric generators for a given excitation frequency and a given amplitude of ambient vibration plays a key role in the design of piezoelectric generators. Therefore, it is crucial to have a proper model that can be used to calculate the power output of designed devices. One method of performing power harvesting is to use PZT materials that can convert the ambient vibration energy surrounding them into electrical energy. This electrical energy can then be used to power other devices or stored for later use. This technology has gained an increasing attention due to the recent advances in wireless and MEMS technology, allowing sensors to be placed in remote locations and operate at very low power. The potential benefits of piezoelectric generators and the advances in low power electronics and wireless sensors are making the future of this technology look very bright.

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